

2mix

NASA TECHNICAL TRANSLATION

NASA TT F-15,688

VARIATIONAL ADJUSTMENT OF STANDARD AND  
ASYNCHRONOUS SATELLITE DATA

T. S. Pagava and M. S. Fuks-Rabinovich

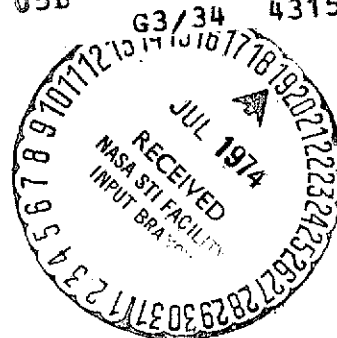
Translation of "Variatsionnoye  
Soglasovaniye Standartnoy i Asinkhronnoy  
Sputnikovoy Informatsii", Meteorologiya  
i Gidrologiya, No. 4, 1974, pp. 55-66.

(NASA-TT-F-15688) VARIATIONAL ADJUSTMENT  
OF STANDARD AND ASYNCHRONOUS SATELLITE  
DATA (Scientific Translation Service)  
23 p HC \$4.25  
22

CSCI 05B

N74-28458

Unclas  
43158



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
WASHINGTON, D. C. 20546  
JULY 1974

VARIATIONAL ADJUSTMENT OF STANDARD AND  
ASYNCHRONOUS SATELLITE DATA

T. S. Pagava\* and M. S. Fuks-Rabinovich

155\*\*

The problem of adjustment of diverse meteorological data is one of the most important ones for purposes of numerical analysis and forecasting. Field adjustment is a necessary final stage in the objective analysis of fields of meteorological elements. Together with the acquisition of asynchronous satellite data observations and preparation of raw data for systems of numerical forecasting through field adjustment, other important problems can be solved, such as the mutual reduction of fields in slightly illuminated regions, the plotting of precise vertical profiles of meteorological elements, filtration of noises in forecasting fields, and so on [3,12-16].

One of the methods of field adjustment is based upon the variational approach [8]. It has been used primarily for adjusting geopotential and wind velocity fields [2, 4-7]. Numerical results were also presented in which the possibility of reduction of the geopotential field on the basis of the wind field by means of the method of variational adjustment (VA) of fields [3] was discussed and other problems mentioned above were solved. The results of these experiments showed that this method may be

---

\* Candidate in Physical-Mathematical Sciences

\*\* Numbers in the margin indicate pagination of original foreign text.

used successfully for purposes of data reduction in rarely studied regions of the globe. The reduction method using the VA system makes it possible to reduce the level of error in analyzing geopotential fields due to the application of data on the wind velocity field (for slightly illuminated regions) by approximately 30% [2]. Particular significance may be attributed to the solution of this problem by the VA method in the tropical belt of the globe, where information on wind is more representatively reflective of the state of atmospheric processes.

Another important application of the VA method involves the possibility of eliminating the "shock" effects in fields of meteorological elements and the high resistance of this method to significant errors in raw data. These properties of the method allow its use for purposes of four-dimensional analysis of regular and asynchronous data [4]. The numerical experiments performed have demonstrated the ability of the VA method to eliminate parasitic effects that arise in a combination of different kinds of information, as well as its high resistance to different kinds of noise.

Article [4] discusses a continuous system for four-dimensional analysis of meteorological data, using the VA method. It was demonstrated that when asynoptic data is used for increasing the accuracy of analysis, particularly in regions with a sparse network of observation stations, the VA procedure is practically advantageous. It yields positive results under different conditions of acquisition of additional observational data, particularly in cases when the incoming asynchronous data does not cover the area of forecasting completely or when it contains significant errors. Thus, with random errors on the order of  $\pm 2$  dam or more, the use of the VA procedure becomes particularly significant from the practical standpoint.

The goal of the present paper consists in generalizing the results of VA fields in three-dimensional analysis with application of standard and asynchronous satellite data on the temperature field (together with data on geopotential fields and wind velocity).

# METHOD OF THREE-DIMENSIONAL VA FIELDS USING TEMPERATURE, GEOPOTENTIAL AND WIND VELOCITY DATA

Let us formulate, according to [8], the VA method with assumption of satisfaction of the ratios of quasistaticity as well as quasigeostrophicity and thermicity of the wind. Let  $u_0, v_0, H_0, T_0$  be the observed values of the components of the wind velocity, geopotential and temperature. The corresponding fields  $u, v, H, T$  must satisfy the following conditions:

$$\left. \begin{aligned} u &= -\frac{1}{l} \frac{\partial H}{\partial y}; \quad v = \frac{1}{l} \frac{\partial H}{\partial x}; \\ \frac{\partial u}{\partial p^*} &= -\frac{1}{l} \frac{\partial T}{\partial y}; \quad \frac{\partial v}{\partial p^*} = \frac{1}{l} \frac{\partial T}{\partial x}; \quad T = \frac{\partial H}{\partial p^*}, \end{aligned} \right\} \quad (1)$$

where  $p^* = -R \ln \frac{p}{\tilde{p}}$ ,

$\tilde{p} = 1000 \text{ mb}$ ,

$R$  is the gas constant

$p$  is the pressure

$l$  is the Coriolis parameter

Then the changes in the fields, i.e., the corrections, introduced for VA,

$$\left. \begin{aligned} u' &= u - u_0; \quad v' = v - v_0; \quad H' = H - H_0; \quad T' = T - T_0 \end{aligned} \right\}$$

will be linked by the relationships

$$\left. \begin{aligned} u' &= -\frac{1}{l} \frac{\partial H'}{\partial y} - u_0 - \frac{1}{l} \frac{\partial H_0}{\partial y}, \\ v' &= \frac{1}{l} \frac{\partial H'}{\partial x} - v_0 + \frac{1}{l} \frac{\partial H_0}{\partial x}, \\ T' &= \frac{\partial H'}{\partial p^*} - T_0 + \frac{\partial H_0}{\partial p^*}. \end{aligned} \right\} \quad (2)$$

157

To find the values  $u'$ ,  $v'$ ,  $H'$ ,  $T'$  it is proposed to solve the variational problem. We are looking for the minimum of the functional

$$I = \int_{\sigma} E^2 dx dy dp^*, \quad (3)$$

where

$$E^2 = \alpha_1^2 u'^2 + \alpha_1^2 v'^2 + \alpha_2^2 H'^2 + \alpha_3^2 T'^2, \quad (4)$$

$\alpha_1, \alpha_2, \alpha_3$  are the weights associated with the Lagrangian multipliers,  $\sigma$  is the area of agreement; at the limits of variation of the corrections the agreements are assumed to be equal to zero ( $\delta H' = 0$ ).

$$\Delta H' - \left( \frac{\alpha_2}{\alpha_1} l \right)^2 H' = \zeta_0 - \Delta H_0 + \left( \frac{\alpha_3}{\alpha_1} l \right)^2 \frac{\partial T_0}{\partial p^*}, \quad (5)$$

where

$$\left. \begin{aligned} \Delta &\equiv \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \left( \frac{\alpha_3}{\alpha_1} l \right)^2 \frac{\partial^2}{\partial p^{*2}}, \\ \zeta_0 &\equiv \frac{\partial v_0}{\partial x} - \frac{\partial u_0}{\partial y} \end{aligned} \right\}$$

with the following condition at the boundary  $H' = 0$ .

If we consider within the limits of quasisolenoidal approximation that

$$u' = -\frac{\partial \psi'}{\partial y} + \frac{\partial \chi'}{\partial x}; \quad v' = \frac{\partial \psi'}{\partial x} + \frac{\partial \chi'}{\partial y}, \quad (6)$$

where  $\psi', \chi'$  are the agreement correction factors for the solenoidal and potential components of the wind velocity vector, with  $\chi'$  being determined from the equation

$$\frac{\partial^2 \chi'}{\partial x^2} + \frac{\partial^2 \chi'}{\partial y^2} = -\left(\frac{\partial u_0}{\partial x} + \frac{\partial v_0}{\partial y}\right),$$

we can derive

$$u_0^* = u_0 + \frac{\partial \chi'}{\partial x}, \quad v_0^* = v_0 + \frac{\partial \chi'}{\partial y}. \quad (7)$$

For a wind velocity field, the agreement corrections in this case will be

$$u^{*'} = u - u_0^*; \quad v^{*'} = v - v_0^*.$$

Hence, we can introduce the potential part of the wind velocity to the discussion.

#### METHOD OF PERFORMING NUMERICAL EXPERIMENTS. BASIC METHODS OF COMPARISON AND EVALUATION OF THE RESULTS

The VA is performed for a region measuring 26 x 22 points in a network with an interval of  $h = 300$  km, covering the territory of Europe and the North Atlantic. An analysis of the raw data is carried out for three surfaces: 850, 500 and 300 mb. For these surfaces, we have the results of an analysis of the geopotential fields, wind velocity and temperatures on 30 April 1965 and 1 May 1965 at 0300. The calculations were made on the basis of the operative three-level quasigeostrophic system of S. L. Belousov [1].

/58

Now let us examine the characteristics of the diagnostic and prognostic fields which are used for evaluation and comparison of the results of the calculations.

#### A. Integral characteristics

The average absolute error in forecasting in a field of geopotential  $\delta_H$  and in the field of the modulus of the velocity of the geostrophic wind  $\delta_V$ :

$$\delta = \frac{1}{N} \sum_{l=1}^N |X_B - X_e|,$$

where  $X_B$  is the value of the estimated meteorological element,

$X_e$  is the value of the meteorological element for the calibration field,

$N$  is the number of points in the field on the basis of which the estimate is computed.

Estimates of the velocity fields of the geostrophic wind are calculated on the basis of 480 points (24 x 20) and of the geopotential field on the basis of 320 points (20 x 16).

The relative error in forecasting in the geopotential field  $\epsilon_H$  and in the field of the modulus of the velocity of the geostrophic wind  $\epsilon_V$ :

$$\epsilon = \frac{\delta}{\delta_\phi};$$

$\delta_\phi = \frac{1}{N} \sum_{i=1}^N |X_e^{\text{orig}} - X_e^{\text{forecast}}|$  is the absolute actual variability of the estimated meteorological element, where  $X_e^{\text{orig}}$  is the actual original field,  $X_e^{\text{forecast}}$  is the actual field of the same meteorological element at the time of forecasting.

The average modulus of the gradient

$$\overline{m}_j = \frac{1}{20} \sum_{i=2}^{21} \sqrt{(X_{i,j+1} - X_{i,j-1})^2 + (X_{i-1,j} - X_{i+1,j})^2},$$

where  $X_{i,j}$  are the values of the estimated meteorological element at the point  $i,j$ ;  $i$  is the number of the line,  $j$  is the number of the column in the grid,  $h$  is the interval of the grid equal to 300 km. The values of the average modulus of the gradient refer approximately to  $52^\circ\text{N}$ , for which  $h \approx 4^\circ$ .

### B. Spectral characteristics

For purposes of a more detailed analysis of the results, we have introduced the spectra of the kinetic energy to the discussion. For the sake of simplicity, we shall limit ourselves to a discussion of the spectra of single-dimensional fields alone. The formation of such a one-dimensional field is accomplished as follows.

Let us calculate for example the average values for each column (or line) of the field. For each averaged field (by lines or columns) we have an expansion in a Fourier series of the function  $f(x)_j - \bar{f}$ , where  $f(x)_j$  are the values of the one-dimensional field in question,  $\bar{f}$  is the average value of a one-dimensional field. For the sake of convenience, we perform reinterpolation of this function on a spherical grid. The components of the spectrum correspond to the sums of the squares of the coefficients of expansion in the Fourier series. The entire spectrum, for the sake of convenience, is broken down into ranges:  $K_0$  is the zonal component,  $K_1$  (for  $5000 < L < 10,000$ ),  $K_2$  ( $4000 < L < 5000$ ),  $K_3$  ( $4000 > L \geq 2400$ ),  $K_4$  ( $24000 > L > 1200$ ),  $K_5$  ( $L < 1200$ ), where  $L$  is the wavelength in kilometers. The ranges  $K_1$  and  $K_2$  are conditionally /59 correspondent to the ultralong waves,  $K_3$  and  $K_4$  to synoptic,  $K_5$  to shortwaves,  $\sum_{i=1}^5 K_i$  is the nonzonal component.



## NUMERICAL EXPERIMENTS USING VA OF DATA ON REAL WIND AND TEMPERATURE

The goal of these numerical experiments consists in studying the problem of the possibility of increasing the quality of forecasting and diagnosis by applying different kinds of additional data by means of VA.

In this section, we will use actual raw data on the geopotential in the calculations.

Let us examine the principal types of calculations.

Type I. The original data are unadjusted observational geopotential fields at the levels of 850, 500 and 300 mb. Here and everywhere below the forecasting is carried out for 24 hours. This variety serves the purposes of comparison.

In all of the other types described below, the original fields at the level of the 850 and 300 mb surfaces were adjusted geopotential fields obtained as a result of variational comparison of actual geopotential fields and fields of geostrophic wind calculated on the basis of the latter. The application of additional data in the various types was carried out for the level of the 500 mb surface.

Type II. At the level of the 500 mb surface with VA the geopotential field  $H_{500}$  is adjusted with a field of velocity of geostrophic wind  $u_{500}$ ,  $v_{500}$ . In this type, agreement with use of the geostrophic wind is accomplished for all three surfaces (850, 500 and 300 mb).

Type III. As the original field of geopotential at the 500 mb level of the surface, the adjusted geopotential field was used, obtained as a result of performing three-dimensional VA

according to Formulae (1) - (5).

In these calculations, the optimum values of the parameters  $a_1, a_2, a_3$  were used. (Selected as in [11] by estimating the prognostic fields). This variety makes it possible to evaluate the role of calculation of additional data on the temperature field in the procedure of three-dimensional VA.

Type IV. The difference between this type and Type II consists in the fact that instead of a geostrophic wind, data on a real wind were used. This type makes it possible to evaluate the role of consideration of data on real wind in the VA procedure.

Type V. This type is similar to Type III, except that the VA procedure is carried out using data on a real wind. Hence, in this type, together with the data on the geopotential, data on temperature and on real wind are considered. This complex type, using the procedure of three-dimensional VA, makes it possible to analyze the results of a joint consideration of different meteorological data.

Let us proceed to an analysis of the results of the calculations.

Table 1 shows the estimates of the prognostic fields for all of the types of VA discussed.

Carrying out the VA procedure in Types II, III, IV and V causes a subsequent decrease in the relative error in prediction  $\epsilon$  (particular attention is concentrated on estimating prediction of  $AT_{500}$ ). Consideration of data on geostrophic wind (Type II) leads to a slight decrease in the values of  $\epsilon$ ,

TABLE 1. ESTIMATES OF PROGNOSTIC FIELDS \*

Surface	Types	Estimates			
		$\delta_H$	$\epsilon_H$	$\delta_V$	$\epsilon_V$
850 mb	I	3,25	0,93	3,12	1,00
	II	3,13	0,90	3,02	0,97
	III	3,09	0,89	3,02	0,97
	IV	3,13	0,90	3,04	0,97
	V	3,10	0,89	3,05	0,98
500 mb	I	3,97	0,88	4,37	0,94
	II	3,84	0,85	4,09	0,88
	III	3,68	0,82	4,09	0,88
	IV	3,76	0,84	4,00	0,86
	V	3,64	0,81	3,98	0,86
	VII	5,16	1,14	5,55	1,20
	VIII	5,01	1,11	5,10	1,10
	IX	4,53	1,01	5,14	1,11
	IX A <sub>n</sub>	n=2	4,61	1,02	5,15
		n=4	4,88	1,08	5,30
		n=6	5,30	1,18	5,52
		n=8	5,83	1,30	5,86
	IX B <sub>n</sub>	n=2	4,51	1,00	5,12
		n=4	4,55	1,01	5,19
		n=6	4,62	1,03	5,34
		n=8	4,73	1,05	5,56
		n=16	5,36	1,19	6,88
	X	4,25	0,94	4,22	0,91
	XI	3,80	0,84	4,18	0,90
300 mb	I	4,70	0,71	6,47	0,92
	II	4,43	0,67	5,88	0,84
	III	4,41	0,67	5,91	0,84
	IV	4,49	0,68	5,90	0,84
	V	4,47	0,68	5,92	0,84

Note: n — magnitude of the error of the temperature field in degrees; IX A<sub>n</sub> — variety with systematic error; IX B<sub>n</sub> — with random error; the values of  $\delta_H$  are given in dams,  $\delta_V$  in meters per second.

\* Translator's note: Commas in numbers represent decimal points.

but using data on the real wind (Type IV) in the VA procedure improves the results of forecasting still further. Consideration of data on temperature in the VA procedure (Type III) also results in a significant decrease in the value of  $\epsilon$ . Finally, joint consideration of data on temperature and real wind (Type V) produces the greatest improvement in the quality of forecasting. In this type, the relative error of forecasting  $\epsilon$  is reduced approximately

10%. On the whole, a similar picture is seen at the 300 and 850 mb surfaces, but the maximum decrease in  $\epsilon$  (in Type V) only reaches 5%, since there is no direct consideration of data on temperature and real wind on these surfaces.

Table 2 lists the spectral characteristics (the spectrum of kinetic energy is taken into account) of the diagnostic fields for all types of agreement of original information. The zonal component  $K_0$  decreases when VA is performed with consideration of the geostrophic wind (Type II). Addition of supplementary information on real wind (Type IV) and joint consideration in the BC procedure of data on the real wind and temperature (Type V) allows a more precise derivation of the value of the total kinetic field energy so that in Types II and III its values are slightly reduced (in comparison with Type I).

/61

TABLE 2. SPECTRAL CHARACTERISTICS OF PROGNOSTIC FIELDS AT  $500^{\circ}$ \*

Types	Intensity of spectral ranges						
	$K_0$	$K_1$	$K_2$	$K_3$	$K_4$	$K_5$	$\sum_{i=1}^5 K_i$
I	13,0	5,8	3,1	3,4	3,5	3,1	18,9
II	11,6	6,4	1,7	3,0	3,0	1,6	15,7
III	11,0	6,7	0,8	3,0	3,0	0,8	14,3
IV	14,4	7,7	1,5	3,5	3,6	1,5	17,8
V	15,3	5,9	1,4	3,6	3,7	1,3	15,9
VII	17,6	3,5	0,9	3,7	3,8	0,9	12,9
VIII	14,4	3,2	0,9	3,1	3,2	0,9	11,2
IX	15,2	4,0	0,6	3,6	3,6	0,9	12,5
IX A <sub>n</sub>	n=2	15,8	3,8	0,6	3,4	0,5	11,7
	n=4	15,7	4,1	0,7	3,2	0,6	12,8
	n=6	15,6	4,5	0,8	3,1	0,8	12,4
	n=8	16,3	3,9	0,5	3,3	0,5	11,5
IX B <sub>n</sub>	n=2	15,7	3,4	0,3	3,2	0,3	10,5
	n=4	15,5	3,0	0,4	2,9	0,4	9,7
	n=6	15,3	2,7	0,6	2,4	0,6	8,8
	n=8	14,8	2,7	1,0	1,9	1,0	8,5
	n=16	17,1	2,8	1,5	2,1	1,5	10,0
X	16,8	7,8	0,8	4,3	4,4	0,8	18,1
XI	17,6	7,3	0,7	4,3	4,4	0,7	17,3

Note: The values of  $K_i$  ( $i=0, \dots, 5$ ) are given in arbitrary units.

\* Translator's note: Commas in numbers represent decimal points.

Attention is also directed to the ranges of synoptic waves ( $K_3$ ,  $K_4$ ) in the kinetic energy spectrum. The intensity of these ranges increases successively for Types III, IV, V, indicating an increase in the activity of the waves in the region of baroclinic instability with consideration of the additional raw data.

As we know from previous papers [3, 4], using the VA procedure makes it possible to reduce considerably the level of the error contained in the raw data concerning geopotential and wind speed. Similar noise filtration is carried out in the temperature field. This high degree of stability of the BC method with respect to significant errors in raw data makes it possible to use it with a combination of diverse and asynchronous data.

An analysis of the prognostic charts and the characteristics of the diagnostic field given above indicates that the simultaneous utilization of data on real wind and temperature, together with factual data on the geopotential, using the VA procedure, allows reduction of the forecasting error by approximately 10%.

#### NUMERICAL EXPERIMENTS ON THE BASIS OF VA USING RAW DATA ON GEOPOTENTIAL, REDUCED ACCORDING TO TEMPERATURE DATA

When sounding the atmosphere using rawinsonds or satellites, the data on temperature constitutes raw data. Therefore, we can attempt to construct a diagram for analysis of raw data which is based primarily upon the data of temperature sounding. In this endeavor, the question arises of what accuracy can be obtained with a geopotential field on the basis of temperature data. It is advantageous in this connection to compare the predictions calculated on the basis of the original geopotential field with those calculated on the basis of the temperature field and actual geopotential data (Type I). /62

Here, as in the previous section, we are dealing with the question of using additional data by means of the VA.

In the experiments discussed below, the geopotential field is reduced only for the 500 mb surface. To reduce it, we use temperature data for the 850 and 500 mb surfaces:

$$H_{500}^B = H_{850} + 6,74 \frac{T_{500} + T_{850}}{2} \lg \frac{85}{50}, \quad (8)$$

where  $T_{500}$  and  $T_{850}$  are the absolute temperatures in degrees.

In the following we shall discuss several varieties of VA, analogous to the varieties discussed in the second sections, but with the difference that instead of the actual field  $H_{500}$  we use a field  $H_{500}^B$  reduced for temperature.

Type VII. As the raw data, we used the field  $H_{500}^B$  and the actual data  $H_{850}$  and  $H_{300}$ . In this type, we do not carry out the VA procedures and it serves primarily for purposes of comparison.

Further types will make it possible to estimate how much improvement there is in the quality of forecasting by using additional data for correction of the original field  $H_{500}^B$ .

Type VIII. The original geopotential field at the 500 mb surface is obtained by means of a procedure of two-dimensional VA  $H_{500}^B$  and geostrophic wind (calculated on the basis of a field  $H_{500}^B$ ).

Type IX. The original geopotential field at the 500 mb level is calculated by means of the procedure for the three-

dimensional VA  $H_{500}^B$  and the temperatures at surfaces 850, 500 and 300 mb. Here additional information is contained primarily in the temperature field at the level of the 300 mb surface, since by calculating  $H_{500}^B$  by Formula (8) we have already used data on temperature at the 850 and 500 mb surfaces. For this variety, we have specially selected the optimum values of the coefficient  $\alpha_3$  in Equation (5).

Type X. This variety is identical to Type VIII, but instead of the geostrophic wind in the VA procedure we have used data on real wind.

Type XI. Here we form a joint analysis of the additional data on real wind and temperature (combination of Types IX and X).

For all of these varieties, the adjusted geopotential fields at the 850 and 300 mb surfaces were calculated in the same manner as for Types II-V.

Let us compare the values of the average moduli of the gradients  $\bar{m}_j$  for varieties I, VII and IX, shown in Figure 1. We can see that the joint consideration in the VA procedure of data on geopotential, temperature and real wind (Type XI) promotes a noticeably more accurate derivation of the geopotential field by comparison with Type VII, in which the VA procedure was not used. Here the standard for comparison is formed by data calculated according to Type I, in which real data on geopotential on all three surfaces are used.

Let us examine the estimates of the forecasting fields for the above varieties, shown in Table 1. Relative estimates of  $\epsilon$  of the forecasts are successively reduced by using data on geostrophic and real wind (Types VIII and X) and on temperature (Type IX). Joint consideration of data on real wind and temperature (Type XI) during VA is instrumental in significantly reducing

(by approximately 30%) the value of  $\epsilon$  in comparison with Type VII, in which the VA procedure is not used. In the case of Type XI, the value of  $\epsilon$  is even about 4% less than for Type I, in which real data on the geopotential at the 850, 500 and 300 mb surfaces are used.

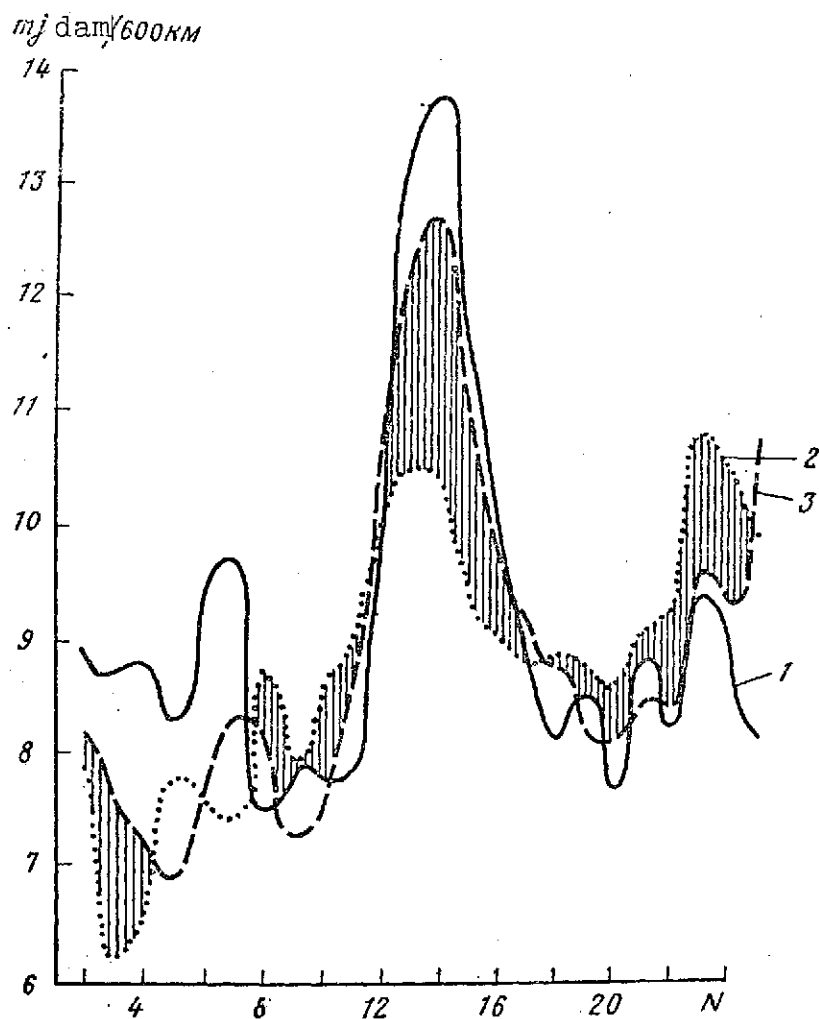


Figure 1. Graph of the changes in  $m_j$  in prognostic geopotential fields for Types I, (1), VII (2), XI (3)

If we now accordingly compare Types I-V with variations VII-XI, each pair of which (for example Types I and VII) is distinguished only by the fact that real fields  $H_{500}$  are used in the former and  $H_{500}^B$  in the latter, we can see the following features. The difference between varieties I and VII (without



using the VA procedure) is quite striking ( $\epsilon$  differs by 26%). However, in Types II and VII, III and IX, IV and X and V and XI the difference gradually decreases, and in the case of the last pair the value of  $\epsilon$  differs only by 3.5%. This means that by taking into account the additional data on temperature and real wind by the VA method it will be possible to supplement to a significant degree the information which is necessary for forecasting the geopotential field.

The spectral characteristics of the fields for Types VII - 164 XI, shown in Table 2, show the same characteristics as for corresponding Types I-V. Here there is also an increase in spectral intensity in the region of baroclinic instability with consideration of the additional data.

Now let us consider the problem of the influence of errors in the original data on forecastings, using the same method as in [3, 9, 10]. Errors (systematic or random) are added to the temperature fields at the 500 and 300 mb surfaces.

From the data in Table 1 and from a visual analysis of the prognostic charts we can see that when we use the VA procedure the error increases quite slowly, with an increase in gradation of error, since significant filtration takes place, particularly when random errors are involved. Considerable stability of the VA method with respect to errors in raw data makes it possible to carry out forecasts under conditions of significant noise. The limiting permissible errors in the temperature field may be considered to be 3-5° C.

Table 2 shows the data on spectral analysis of the kinetic energy of the diagnostic fields. On the basis of these data we can determine the limiting raw-data error levels for the temperature fields in various spectral ranges.

Let us use, for example, as the criterion for loss of predictability of movements in a given wave range the magnitude of the error which leads to an increase in the intensity of the range by 10% (this value must be selected as a function of requirements for forecasting accuracy). In this case, this value is equal to the maximum increase in the average values of  $\epsilon$  for an error equal to twice the average observational error (according to the data in Table 1). Then the zonal component will be predicted for all of the applied values of errors and the nonzonal component will lose its predictability at a level of initial systematic error on the order of  $2-4^{\circ}\text{C}$ , and for random error only at a level on the order of  $4-6^{\circ}\text{C}$ . According to the data in this table, however, we can make comparison and get some idea of the loss of predictability for various levels of error for different spectral ranges.

#### FOUR-DIMENSIONAL ACQUISITION OF ASYNCHRONOUS SATELLITE DATA FROM OBSERVATIONS USING FIELD VA

The above-described VA procedure for fields was used for plotting the system of four-dimensional analysis of asynchronous satellite data. Asynchronous observation data, reaching the forecasting area, cover the territory in strips with a width on the order of 1500 km, extending almost in the meridional direction. Data arrives regularly every 24 hours and gradually covers the entire forecasting area in a direction running from west to east. Thus, the entire forecasting area is covered by asynchronous data in five days. After each reception of synchronous data, the VA

procedure for the field is carried out, and then forecasting is done at the moment of arrival of new asynoptic observation data. Following reception of the last part of the supplementary data, the final VA of the fields is carried out and the geopotential is calculated on the basis of the field which is created in this fashion to give a prediction for the days which is compared with actual data. Asynchronous data are imitated by using actual geopotential data during subsequent periods of observation (at 0300 on 27 April - 1 May 1965). When using the two-dimensional VA procedure, data on the geostrophic wind are used (as in Type II), while in three-dimensional VA, together with the data on the geostrophic wind, use is made of temperature data (as in Type III).

Table 3 shows the average absolute errors in forecasting fields with a geopotential and a wind velocity modulus  $\delta_H$

TABLE 3. EVALUATIONS OF FORECASTING FIELDS ON A 500 mB SURFACE (FOUR-DIMENSIONAL ACQUISITION OF ASYNCHRONOUS INFORMATION)\*

Eval.	Variations														
	I					II					III				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
$t_H$	4,2	6,6	8,0	9,1	11,0	—	—	—	—	—	—	—	—	—	—
$D_H$	—	—	—	—	—	95	93	95	86	87	92	92	95	81	85
$\delta_V$	5,5	6,3	7,4	8,8	9,6	—	—	—	—	—	—	—	—	—	—
$D_V$	—	—	—	—	—	88	87	86	72	76	88	85	85	70	72

Note: The values of  $D_H$ ,  $D_V$  are given in percents; the remaining notation is the same as in Table 1.

\* Translator's note: Commas in numbers represent decimal points.

on the 500 mb surface, calculated after the arrival of each "band" of information (1-5) for the type, when the VA procedure was not used in four-dimensional analysis (as in Type I). Furthermore, in this same table we can see the ratios of the values  $\delta_H$  and  $\delta_V$  for two types of data adjustment (a) by using the three-dimensional VA procedure (Formula 5), and (b) by using the two-dimensional procedure VA ( $\alpha_3 = 0$  in Formula 5) to the corresponding values of  $\delta_H$  and  $\delta_V$  for the variety without using VA. These values are designated  $D_H$  and  $D_V$  and are given in percentages.

Let us note in particular that forecasting on the basis of data obtained by using VA is subject to much less error than forecasting using nonadjusted raw data. The differences in Types II and III VA forecasting errors are comparatively small; nevertheless, the use of three-dimensional VA will reduce errors even more significantly.

On the whole, using VA in four-dimensional analysis makes it possible to reduce the mean absolute forecasting error for geopotential following receipt of all data by approximately 15-20%, and the average absolute error in the modulus of the wind velocity at 25-30%. Visual analysis of prognostic charts also indicates the advantages of using the VA procedure for fields with four-dimensional acquisition of asynchronic data.

## REFERENCES

1. Belousov, S. L. Experience in Operative Prediction of Altitude Baric Charts on Three Levels. Trudy TsIP, No. 99, 1960.
2. Zin'kovskaya, T. S. The Analysis of Meteorological Data Using the Variational Method of Agreement of Fields. Trudy GMTs, No. 100, 1972.
3. Zin'kovskaya, T. S. Reducing the Geopotential Field on the Basis of the Wind Velocity Field Using the Variational Method of Agreement of Fields. Trudy GMTs, No. 58, 1971.
4. Zin'kovskaya, T. S. Diagram of Four-Dimensional Analysis of Meteorological Data Using the Variational Method of Agreement of Fields. Trudy GMTs, No. 123, 1973.
5. Katkov, V. L., and A. S. Marchenko. Geostrophic Agreement of Geopotential Fields for Barotropic Forecasting. Izv. AN SSSR, Physics of the Atmosphere in Motion, Vol. III, No. 2, 1967.
6. Kluge, I. Using Wind Data in the Objective Analysis of an Altitude Baric Field. Trudy GGO, No. 267, 1970.
7. Kostyukov, V. V. and A. S. Marchenko. Adjustment of Initial Wind Fields and Geopotential Fields for a Barotropic Forecast. Meteorologiya i Gidrologiya, No. 5, 1969..
8. Sasaki, Ye. Numerical Variational Method of Analysis and Forecasting. In the book: Trudy vtorogo Tokiyskogo Simpoziuma po Chislennym Metodam Prognoza Pogody (Transactions of the Second Tokyo Symposium on Numerical Methods of Weather Forecasting). Leningrad, Gidrometeoizdat, 1971.
9. Fuks-Rabinovich, M.S. A Method of Estimating the Influence of Inaccuracy of Raw Data on the Results of Forecasting, Calculated with the Aid of Various Finite-Difference Algorithms of the Solution of Prognostic Levels. Trudy GMTs SSSR, No. 29, 1968.

10. Fuks-Rabinovich, M. S. Estimating the Influence of Raw Data Accuracy on Geopotential and Wind Velocity Forecasting Using a Primitive Barotropic Model of the Atmosphere. Trudy GMTs, No. 71, 1970.
11. Fuks-Rabinovich, M.S. Problem of the Variational Method of Agreement of Geopotential and Wind Speed Fields within the Framework of a Solenoidal Model of the Atmosphere. Trudy, GMTs, No. 71, 1970.
12. Duquet, R. F. et al. Objective Cross Section Analysis. J. Appl. Meteorol. Vol. 5, No. 3, 1966.
13. Sasaki, Y. An Objective Analysis Based on the Variational Method. J. Meteorol. Soc. Japan. Vol. 36, No. 3, 1958.
14. Sasaki, Y. Numerical Variational Analysis Formulated under the Constraints as Determined by Longwave Equations and a Low-Pass Filter. Mon. Weather Rev. Vol. 98, No. 12, 1970.
15. Sasaki, Y. A Theoretical Interpretation of Anisotropically Weighted Smoothing of the Basis of Numerical Variational Analysis. Mon. Weather Rev., Vol. 99, No. 9, 1971.
16. Stephens, Y. Y. Variational Resolution of Wind Components. Mon. Weather Rev. Vol. 96, No. 4, 1968.

Translated for National Aeronautics and Space Administration under contract No. NASw 2483, by SCITRAN, P. O. Box 5456, Santa Barbara, California 93108.